COMMUNICATION METHOD UTILIZING OPTICAL SOLUTION AND COMMUNICATION SYSTEM USING THE METHOD

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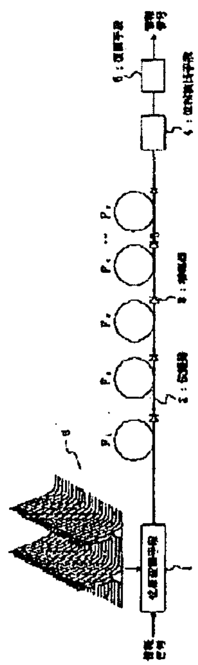
Abstract of **JP8201861**

PURPOSE: To provide a communication method utilizing optical soliton and by which further abundant information can be transmitted and information transmission can be carried out stably as compared with a characteristic frequency communication and provide a communication system of the method. CONSTITUTION: Regarding a communication system in which optical solitons are sent in a transmitting path consisting of optical fibers and having dispersed properties and non-linearity and transmitted through the path; the communication system is provided with a phase modulating means 1 to modulate the phases of optical solitons corresponding to information signals, the transmitting path 2 to transmit the information signals, a phase detecting means 4 to detect the phases of optical solitons based on the initial phases of the optical solitons, and a demodulating means 5 to demodulate the information signals of the optical solitons transmitted from the phase detecting means.



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10/18				
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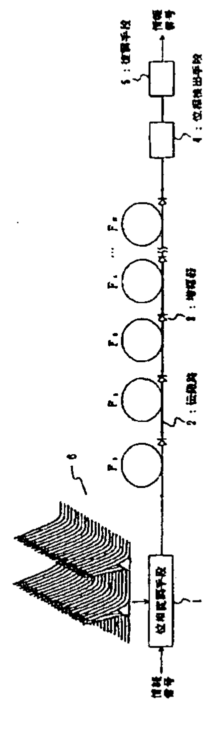
(54)【発明の名称】　光ソリトンを用いる通信方法及びその通信システム

(57)【要約】

【目的】　より多くの情報を伝送でき、また、固有値通信に比べてより安定な情報伝達を行うことができる光ソリトン用いる通信方法及びその通信システムを提供する。

【構成】　光ファイバー等の分散性と非線形性を有する伝搬路に光ソリトンを入力させて伝搬させる通信システムにおいて、情報信号に対応して、光ソリトンの位相を変調する位相変調手段１と、情報信号を伝送する伝搬路２と、光ソリトンの初期位相に基づいて光ソリトンの位相を検出する位相検出手段４と、その光ソリトンの位相から伝送された情報信号を復調する復調手段５とを具備する。



する位相検出手段と、その光ソリトンの位相から伝送された情報信号を復調する復調手段とを設けるようにしたものである。

【0008】(7) 上記 (6) 記載の光ソリトンを用いる通信システムにおいて、パルスの中心位置のずれ、位相ずれのゆらぎを抑える光ソリトンのパラメータの伝送制御装置を設けるようにしたものである。

【0009】

【作用】本発明によれば、光ソリトンを用いる新しい通信方式として、光ソリトンを搬送波として用い、情報信号により、位相変調を行い、情報信号を伝送する通信方式を提案する。従来の光ソリトン通信がパルスの有無に情報をのせる方式であったことに対して、この方式はソリトンパルス列を構成する各パルスの位相、又は隣接ソリトン間の位相差に情報をのせる方式である。

【0010】すなわち、光ソリトンは、（1）隣接する２つのソリトンの間の位相をそれぞれ独立に選択できる。（2）ソリトンパルス内の位相は時間によらず一定である、という２つの特徴を持っている。この特徴を利用すると、光ソリトンの位相を変調し、これに情報をのせて通信を行う新しい通信方式を構築することができる。

【0011】また、搬送路上で周期的な増幅や周波数フィルタ及び非線形利得等の光ソリトンのパラメータの制御装置を用いて伝送制御を行い、エラーの少ない伝送を行うことができる。

【0012】

【実施例】以下、本発明の実施例を図面を参照しながら説明する。本発明によれば、ソリトンパルスの初期位相は、光パルスが非線形シュレディンガー方程式に従って伝搬する限り保存され、また、パルスの中で一定である。このことよって、光ソリトンを用いる場合にも、コヒーレント光通信の場合と同様に、ソリトンパルス列の各々のパルスの位相に情報信号をのせることができる。

【0013】図１は本発明の光ソリトンを用いる通信シ＊

＊ステムの一実施例を示すブロック図、図２は光ソリトンのシミュレーションを行った結果を示す図である。この図において、位相変調手段１は、通信しようとする情報信号に対応して、搬送波である光ソリトン６を位相変調する手段である。その位相変調手段１で位相変調された光ソリトンパルスを、光ファイバーなどの分散性と非線形性を有する伝搬路２の入力端子に入力して伝搬する。その場合、光ソリトンパルスの初期位相は、光ソリトンパルスが非線形シュレディンガー方程式に従って伝搬する限り保存され、パルス中で時間によらず一定である性質があり、受信側では、この初期位相に基づいて、その位相を位相検出手段４で検出し、復調手段５で伝送された情報信号を復調して、受信するようにしている。ここで、位相変調手段１としては、例えば、ＵＴ Ｐｈｏｔｏｎｉｃｓ社のＡｎｎｅａｌｅｄ Ｐｒｏｔｏｎ Ｅｘｃｈａｎｇｅ（ＡＰＥ™）プロセスを用いてＸ−ｃｕｔのＬｉＮｂＯ$_3$材料上に回路が構築されたデバイス等を用いることができる。また、３は増幅器である。

【0014】本発明では、このような光ソリトンを搬送波として用いる位相変調方式の伝送特性について検討する。位相変調を行う場合、位相を情報信号によって連続的に変調し、アナログ伝送を行ったり、多値信号を伝送することも可能であるが、ここでは、光ソリトンを用いたＰＳＫ（位相に情報信号をのせるディジタル位相変調：フェーズ・シフト・キー）方式に相当する２値デジタル信号の伝送を考える。

【0015】そこで、モデル方程式について説明する。光ファイバー中における光パルスの振る舞いを記述するモデル方程式として、非線形シュレディンガー方程式にファイバー損失を補うための周期的な増幅、伝送制御のための周波数フィルタ及び非線形利得を表す項が摂動として加わった方程式を考える。

【0016】

【数１】

$$i\frac{\partial q}{\partial Z}+\frac{1}{2}\frac{\partial^2 q}{\partial T^2}+|q|^2 q=i\delta q+i\beta\frac{\partial^2 q}{\partial T^2}+i\gamma|q|^2 q+S(T,Z) \qquad \cdots(1)$$

【0017】ここで、Ｔ及びＺは規格化された時間及び距離、ｑは規格化された電界包絡線のガイディング・センタ振幅を表す。δ及びβは周波数フィルタの中心周波数における余剰利得及び周波数特性の曲率、γは非線形利得係数、Ｓ（Ｔ，Ｚ）は増幅器で加わる自然放出雑音を表す。ソリトンパルスはパルス波形の初期歪、増幅器雑音及び隣接ソリトンとの相互作用などによって影響を受ける。そのため、周波数フィルタや非線形利得等によ※

※る伝送制御が必要となる。

【0018】次に、パルス波形の初期歪及び増幅器雑音の影響について説明する。前記式（１）の右辺に示す摂動項によるソリトンの挙動を知るために、光パルスの断熱的な変化を表すダイナミカル方程式を導く。まず、光パルスは次式で表されるものとする。

【0019】

【数２】

$$q(T,Z)=\eta(Z)\,\mathrm{sech}[\eta(Z)\{T-T_0(Z)\}]\,\mathrm{exp}[-ik(Z)T+i\theta_0(Z)] \qquad \cdots(2)$$

【0020】この式（２）は非線形シュレディンガー方程式の１−ソリトン解の振幅（または幅）及び速度（または周波数）を表すパラメータη及びｋが伝搬するに従って、断熱的に変化することを表している。また、ソリトンの中心位置T_0及び位相θ_0もＺの関数である。前記（２）を式（１）に代入し、さらに、摂動逆散乱法を用いることによって次式を得る。

【0021】

式（6）において、$S_\eta=S_k=S_{T_0}=S_{\theta_0}=0$とおき、Z＝0における波形歪の初期値を（$\Delta\eta$，$\Delta k$，$\Delta T_0$，$\Delta\theta_0$）＝（$\tilde{\eta}$，$\tilde{k}$，$\tilde{T}_0$，$\tilde{\theta}_0$）とおく。伝送制御を行わない場合、及び行った場合の式（6）の初期値問題の解は次式で与えられる。

$$\left\{\begin{array}{lcl}\Delta\eta=\tilde{\eta} & \longleftrightarrow & \tilde{\eta}\,e^{-4\delta Z}\\ \Delta k=\tilde{k} & \longleftrightarrow & \tilde{k}\,e^{-4\beta Z/3}\\ \Delta T_0=\tilde{T}_0-\tilde{k}Z & \longleftrightarrow & \tilde{T}_0-\dfrac{3\tilde{k}}{4\beta}(1-e^{-4\beta Z/3})\\ \Delta\theta_0=\tilde{\theta}_0+\tilde{\eta}Z & \longleftrightarrow & \tilde{\theta}_0+\dfrac{\tilde{\eta}}{4\delta}(1-e^{-4\delta Z})\end{array}\right. \quad\cdots(7)$$

【0030】この式（7）より、伝送制御を行わない場合には、パルスの中心位置及び位相のずれには伝搬距離に比例して増大するのに対して、伝送制御を行うと、初期歪で決まる定数のずれしか生じないことが分かる。次に、パルス波形に初期歪がないとして、増幅器の自然放出雑音の影響と伝送制御の効果について検討する。

【0031】前記式（6）の右辺のS_i，（$i=\eta$，k，T_0，θ_0）はランダムな揺動力を表すから、この＊＊場合、前記式（6）はランジュバン方程式となる。S_iの自己相関関数が前記式（4）で与えられるとして、伝送制御を行わない場合、及び行った場合の（$\Delta\eta$，Δk，ΔT_0，$\Delta\theta_0$）の2乗平均値（分散）を求めると、

【0032】

【数8】

$$\left\{\begin{array}{lcl}\langle\Delta\eta^2(Z)\rangle=2\mu_\eta Z & \longleftrightarrow & \dfrac{\mu_\eta}{4\delta}(1-e^{-8\delta Z})\\ \langle\Delta k^2(Z)\rangle=2\mu_k Z & \longleftrightarrow & \dfrac{3\mu_k}{4\beta}(1-e^{-8\beta Z/3})\\ \langle\Delta T_0^2(Z)\rangle=\dfrac{2}{3}\mu_k Z^3+2\mu_{T_0}Z & \longleftrightarrow & \dfrac{9\mu_k}{64\beta^3}(8\beta Z-9+12e^{-4\beta Z/3}-3e^{-8\beta Z/3})+2\mu_{T_0}Z\\ \langle\Delta\theta_0^2(Z)\rangle=\dfrac{2}{3}\mu_\eta Z^3+2\mu_{\theta_0}Z & \longleftrightarrow & \dfrac{\mu_\eta}{64\delta^3}(8\delta Z-3+4e^{-4\delta Z}-e^{-8\delta Z})+2\mu_{\theta_0}Z\end{array}\right. \quad\cdots(8)$$

【0033】となる。この式（8）より増幅器雑音によるパルスの中心位置のずれΔT_0（Gordon－Haus効果によるタイミングジッタ）と同様、位相ずれ$\Delta\theta_0$の揺らぎも伝送距離の3乗に比例して増大する効果を伝送制御を行うことによって伝送距離に比例する効果に抑えられることが分かる。また、ΔT_0はβが、$\Delta\theta_0$はδがそれぞれ大きいほど抑えられる。

【0034】さらに、前記式（8）から光ソリトンを用いたIM－DD方式及びPSK方式の伝送距離と誤り率※※の関係を求める。ΔT_0及び$\Delta\theta_0$の確率分布はガウス分布で表されるものと仮定する。また、IM－DD方式では、T_0がパルスの電力半値幅$2\log_e(\sqrt{2}+1)$の1／2以上ずれる場合は誤りと見なし、PSK方式では、θ_0が$\pi/2$以上ずれる場合を誤りと見なすことにする。このとき、誤り率P_eはそれぞれ

【0035】

【数9】

$$P_e^{PSK}=\mathrm{erfc}\left[\frac{\pi/2}{\sqrt{2\langle\Delta\theta_0^2(Z)\rangle}}\right],\quad P_e^{IM-DD}=\mathrm{erfc}\left[\frac{\log_e(\sqrt{2}+1)}{\sqrt{2\langle\Delta T_0^2(Z)\rangle}}\right]\quad\cdots(9)$$

で与えられる。ここでerfc［・］は誤差補関数である。

【0036】また、前記式（4）のμは、

【0037】

【数10】

$_t$ 及びΔΘ（Z）を求めた。前記式（14）及び数値計算によって求めた初期パルス間隔T_0 とIM－DD方式で誤りが生ずる距離Z_t の関係を図4に示す。また、伝送制御を行った場合にも、位相差ΔΘは変化しない。よって、ソリトン間の相互作用に対しては位相差は変化せず、さらに、ソリトンの位相はパルスの中で一定であり、パルスの裾の部分でも情報信号の識別を行うことができるため、IM－DD方式に比べてPSK方式の方が誤り率を小さくできることが分かる。

【0048】このように、光ソリトンを搬送波として用いる位相変調による通信方式について検討を行った。パルス波形の初期歪、増幅器雑音、ソリトン間相互作用がパルスの中心位置及び位相に及ぼす影響、周波数フィルタと非線形利得による伝送制御の効果を摂動法によって定量的に評価し、ソリトンを用いたIM－DD方式とPSK方式の比較を行った。

【0049】その結果、PSK方式の伝送特性はIM－DD方式に比べて、増幅器雑音に対しては大差はないが、ソリトン間相互作用に対して影響を受け難いことが明らかになった。また、雑音に対する伝送制御の効果が大きいことが分かった。コヒーレント光通信方式のうち、位相に情報信号をのせるディジタル位相変調方式（PSK方式）との比較を行い、その長短を明らかにすることは今後の課題である。

【0050】なお、本発明は上記実施例に限定されるものではなく、本発明の趣旨に基づいて種々の変形が可能であり、これらを本発明の範囲から排除するものではない。

【0051】

【発明の効果】以上、詳細に説明したように、本発明によれば、以下のような効果を奏することができる。

（1）より多くの情報を伝送でき、また、固有値通信に比べてより安定な情報伝達を行うことができる。

【0052】（2）この光ソリトンの位相変調制御による通信は、高速度光通信、マルチメデア用基幹回線、高信頼度光通信として、発展が期待される。

【図面の簡単な説明】

【図1】本発明の光ソリトンを用いる通信システムの一実施例を示すブロック図である。

【図2】光ソリトンのシミュレーションを行った結果を示す図である。

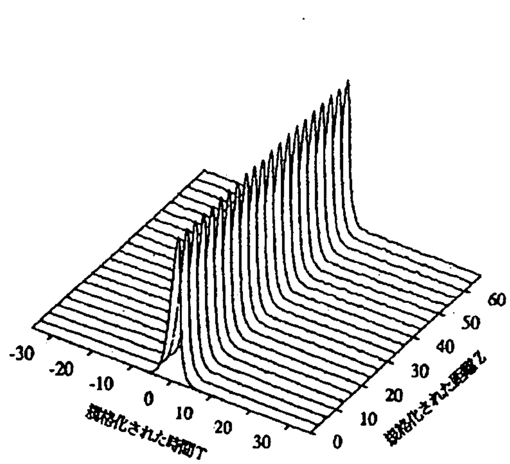
【図3】光ソリトンを用いたIM－DD方式及びPSK方式の伝送距離との誤り率の関係を示す図である。

【図4】光ソリトンを用いたIM－DD方式における初期パルス間隔と相互作用によって誤りが生じる距離の関係を示す図である。

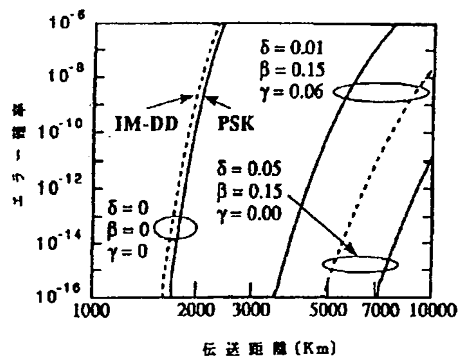
【符号の説明】

1 位相変調手段
2 伝搬路
3 増幅器
4 位相検出手段
5 復調手段
6 光ソリトン

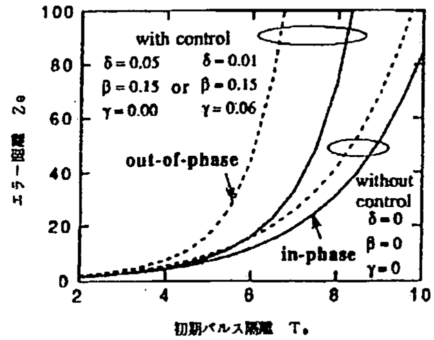
【図2】



【図3】



【図4】


with control
δ=0.05
β=0.15
γ=0.00
or
δ=0.01
β=0.15
γ=0.06
out-of-phase
in-phase
without
control
δ=0
β=0
γ=0
エラー距離 Zo
初期パルス間隔 To
100
80
60
40
20
0
2
4
6
8
10

PATENT ABSTRACTS OF JAPAN

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(71)Applicant : RES DEV CORP OF JAPAN

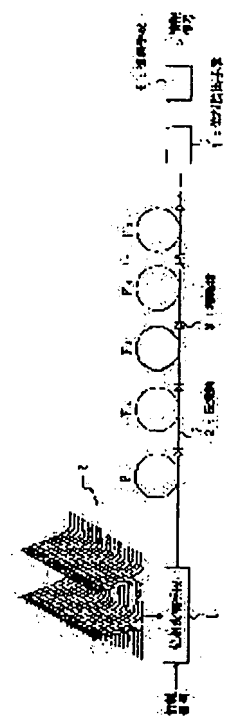
(72)Inventor : HASEGAWA AKIRA

(54) COMMUNICATION METHOD UTILIZING OPTICAL SOLUTION AND COMMUNICATION SYSTEM USING THE METHOD

(57)Abstract:

PURPOSE: To provide a communication method utilizing optical soliton and by which further abundant information can be transmitted and information transmission can be carried out stably as compared with a characteristic frequency communication and provide a communication system of the method.

CONSTITUTION: Regarding a communication system in which optical solitons are sent in a transmitting path consisting of optical fibers and having dispersed properties and non-linearity and transmitted through the path; the communication system is provided with a phase modulating means 1 to modulate the phases of optical solitons corresponding to information signals, the transmitting path 2 to transmit the information signals, a phase detecting means 4 to detect the phases of optical solitons based on the initial phases of the optical solitons, and a demodulating means 5 to demodulate the information signals of the optical solitons transmitted from the phase detecting means.



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[Date of final disposal for application]	
[Patent number]	3226739
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[Number of appeal against examiner's decision of rejection]	
[Date of requesting appeal against examiner's decision of rejection]	
[Date of extinction of right]	

DESCRIPTION OF DRAWINGS

[Brief Description of the Drawings]
[Drawing 1] It is the block diagram showing one example of the communication system using the optical soliton of this invention.
[Drawing 2] It is drawing showing the result of having performed simulation of an optical soliton.
[Drawing 3] It is drawing showing the relation of an error rate with the transmission distance of the IM-DD method using an optical soliton, and an PSK method.
[Drawing 4] It is drawing showing the relation of the distance which an error produces by the initial pulse separation and the interaction in the IM-DD method using an optical soliton.
[Description of Notations]
1 Phase Modulation Means
2 Propagation Path
3 Amplifier
4 Phase Detection Means
5 Recovery Means
6 Optical Soliton

[Translation done.]

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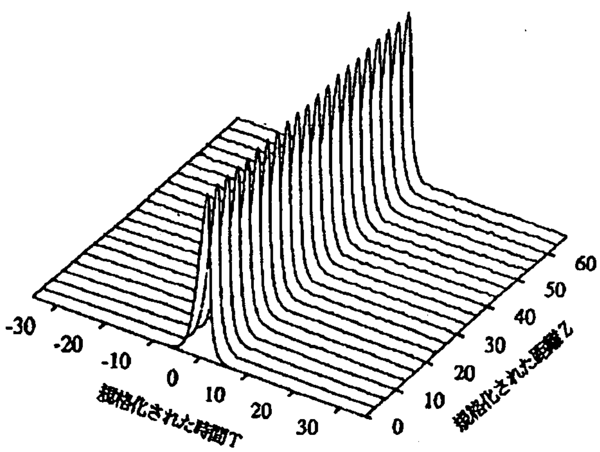
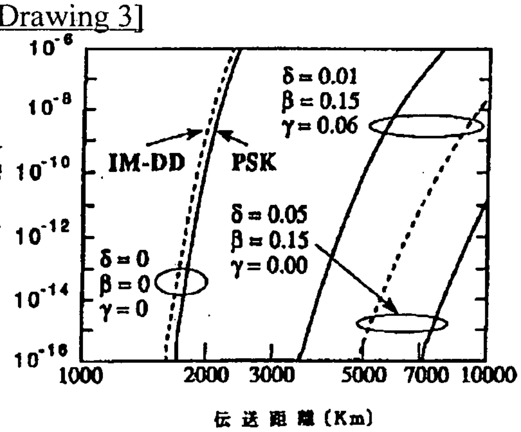
3.In the drawings, any words are not translated.

DRAWINGS

[Drawing 2]

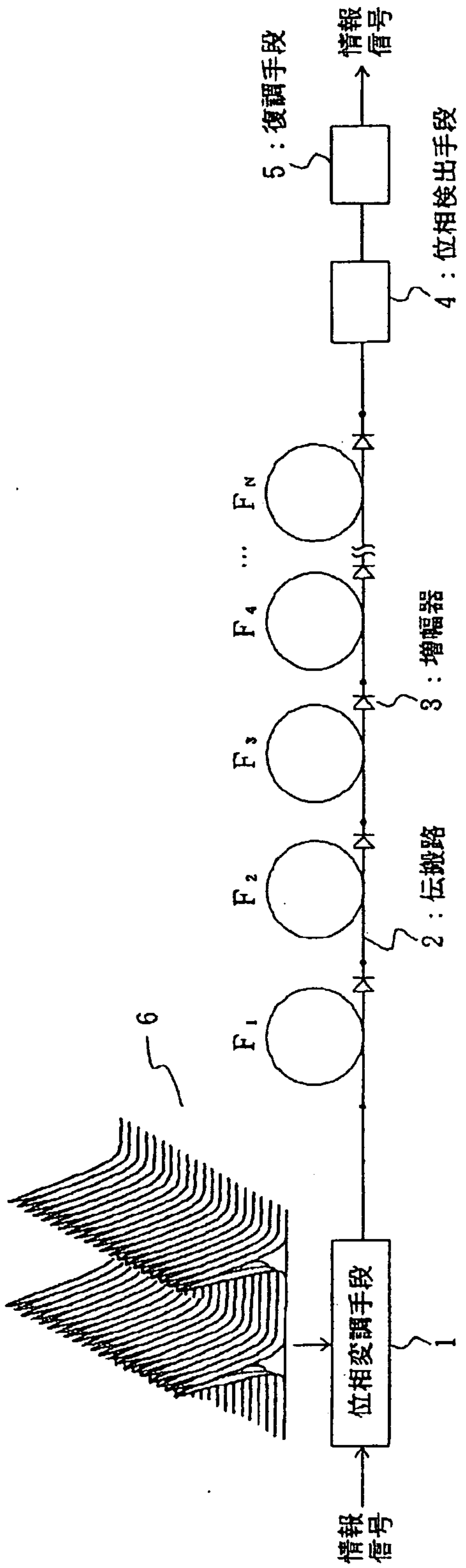


[Drawing 3]

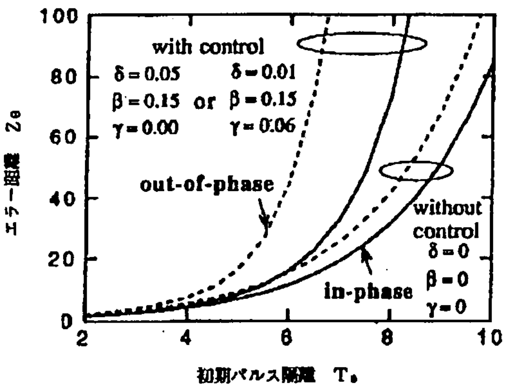


~~[Drawing 1]~~

Drawing 1



~~[Drawing 4]~~



Drawing 4

[Translation done.]

* NOTICES *

DETAILED DESCRIPTION

[Detailed Description of the Invention]
[0001]
[Industrial Application] This invention relates to the communication mode which uses an optical soliton, and relates to the communication mode which performs a phase modulation corresponding to an information signal, and transmits an information signal especially, using an optical soliton as a subcarrier.
[0002]
[Description of the Prior Art] Current and the fiber-optics-communication method introduced in commercial are intensity modulation direct detection methods (IM-DD method), and is a communication mode which carries and transmits an information signal to the existence of a pulse. Moreover, taking advantage of the coherence nature of a laser beam, research is briskly recommended also for the coherent light communication mode which puts an information signal on the property as a wave called the frequency and phase of light. On the other hand, research is energetically recommended also for the fiber-optics-communication method using an optical soliton. Also in this case, the information signal is put on the existence of a SORITO pulse, and is equivalent to the IM-DD method using an optical soliton.
[0003] Moreover, the artificer of this application has proposed the characteristic value communication mode which can transmit information also to a remote place using the property in which the characteristic value of a light wave does not already change according to travelling distance even if dispersibility and non-linearity exist in a propagation track (refer to JP,5-232523,A).
[0004]
[Problem(s) to be Solved by the Invention] However, by the phase-modulation communication link formula using the above-mentioned conventional light wave, distortion arises on the structure of an optical fiber in the phase by which the nonlinearity that the dispersibility and the wave that group velocity distributes were distorted was modulated by influencing, and quality optical communication is rather difficult. This invention aims at offering the correspondence procedure using the optical soliton which can remove this conventional trouble, and can transmit more information, and can perform more stable signal transduction compared with a characteristic value communication link, and its communication system.
[0005]
[Means for Solving the Problem] In the correspondence procedure which is made to input an optical soliton into the propagation path which has the dispersibility and nonlinearity of (1) optical fiber etc., and is made to spread in order that this invention may attain the above-mentioned purpose The initial phase of an optical soliton pulse is saved as long as an optical soliton pulse spreads according to a nonlinear Schrodinger equation. It is not based on time amount in a pulse, but an information signal

performs the phase modulation of an optical soliton using a fixed property, using an optical soliton as a subcarrier, an information signal is transmitted through a propagation path, and it restores to the transmitted information signal based on the initial phase of an optical soliton.
[0006] (2) Put an information signal on the phase of the pulse which constitutes an optical soliton pulse train in the correspondence procedure using the optical soliton of the above-mentioned (1) publication.
(3) In the correspondence procedure using the optical soliton of the above-mentioned (2) publication, perform transmission control of the parameter of an optical soliton and suppress fluctuation of a gap of the center position of a pulse, and a phase shift.
[0007] (4) Put an information signal on the phase contrast between contiguity solitons in the correspondence procedure using the optical soliton of the above-mentioned (1) publication.
(5) Transmit 0 or pi, and a nothing information signal for an initial phase difference in the correspondence procedure using the optical soliton of the above-mentioned (4) publication.
(6) Establish a phase modulation means to modulate the phase of an optical soliton, the propagation path which transmits an information signal, a phase detection means to detect the phase of an optical soliton based on the initial phase of an optical soliton, and a recovery means to restore to the information signal transmitted from the phase of the optical soliton, corresponding to an information signal in the communication system which is made to input an optical soliton into the propagation path which has the dispersibility and nonlinearity of an optical fiber etc., and is made to spread.
[0008] (7) Form the transmission control unit of the parameter of the optical soliton which suppresses fluctuation of a gap of the center position of a pulse, and a phase shift in the communication system using the optical soliton of the above-mentioned (6) publication.
[0009]
[Function] According to this invention, as a new communication mode using an optical soliton, using an optical soliton as a subcarrier, a phase modulation is performed and the communication mode which transmits an information signal is proposed with an information signal. It is the method which puts information on the phase of each pulse from which this method constitutes a soliton pulse train to the conventional optical soliton communication link having been the method which puts information on the existence of a pulse, or the phase contrast between contiguity solitons.
[0010] That is, an optical soliton can choose independently the phase between two solitons which carry out (1) contiguity, respectively. (2) It has two descriptions that the phase within a soliton pulse is not based on time amount, but is fixed. If this description is used, the phase of an optical soliton can be modulated and the new communication mode which communicates by putting information on this can be built.
[0011] Moreover, transmission control can be performed using the control unit of the parameter of optical solitons, such as periodic magnification, and a frequency filter, nonlinear gain, by conveyance on the street, and little transmission of an error can be performed.
[0012]
[Example] Hereafter, the example of this invention is explained, referring to a drawing. According to this invention, the initial phase of a soliton pulse is saved as long as a light pulse spreads according to a nonlinear Schrodinger equation, and it is fixed in a pulse. this -- as well as the case of coherent optical communication when using an optical soliton, an information signal can be put on the phase of each pulse of a soliton pulse train.
[0013] The block diagram showing one example of the communication system with which drawing 1 uses the optical soliton of this invention, and drawing 2 are drawings showing the result of having performed simulation of an optical soliton. In this drawing, the phase modulation means 1 is a means which carries out the phase modulation of the optical soliton 6 which is a subcarrier corresponding to the information signal which is going to communicate. With the phase-modulation means 1, the optical soliton pulse by which the phase modulation was carried out is inputted into the input terminal of the

propagation path 2 which has the dispersibility and nonlinearity of an optical fiber etc., and is spread. In that case, the initial phase of an optical soliton pulse is saved as long as an optical soliton pulse spreads according to a nonlinear Schrodinger equation, is not based on time amount in a pulse, but has a fixed property, and it detects that phase with the phase detection means 4, restores to the information signal transmitted with the recovery means 5, and he is trying to receive in a receiving side based on this initial phase. Here, as a phase modulation means 1, it is UT, for example. Annealed of Photonics Proton The device with which the circuit was built on the LiNbO3 ingredient of X-cut using the Exchange (APETM) process can be used. Moreover, 3 is amplifier.
[0014] This invention examines the transmission characteristic of the PE which uses such an optical soliton as a subcarrier. When performing a phase modulation, a phase is continuously modulated with an information signal, an analog transmission is performed, or although it is also possible to transmit a multiple-value signal, transmission of the binary digital signal equivalent to the PSK (about [digital one which puts an information signal on a phase] phase modulation : phase shift key) method which used the optical soliton is considered here.
[0015] Then, the method of a model explains an equation. The term which expresses the frequency filter and nonlinear gain for the periodic magnification for compensating fiber loss and transmission control with a nonlinear Schrodinger equation as an equation considers the equation added as a perturbation for the method of the model which describes behavior of the light pulse in an optical fiber.
[0016]
[Equation 1]

$$i\frac{\partial q}{\partial Z}+\frac{1}{2}\frac{\partial^2 q}{\partial T^2}+|q|^2 q=i\delta q+i\beta\frac{\partial^2 q}{\partial T^2}+i\gamma|q|^2 q+S(T,Z) \quad \cdots (1)$$

[0017] Here, the time amount by which T and Z were standardized and distance, and q express the guy DINGU center amplitude of the standardized electric-field envelope. The spontaneous emmision noise which surplus gain [in / in delta and beta / a frequency center of filter frequency] and the curvature of frequency characteristics, and gamma join with a nonlinear gain coefficient, and S (T, Z) joins with amplifier is expressed. A soliton pulse is influenced by an interaction with initial distortion, amplifier noise, and contiguity soliton of pulse shape etc. Therefore, the transmission control by the frequency filter, nonlinear gain, etc. is needed.
[0018] Next, the initial distortion of pulse shape and the effect of an amplifier noise are explained. In order to know the behavior of the soliton by the perturbation term shown in the right-hand side of said equation (1), the Dina Michal equation showing an adiabatic change of a light pulse is drawn. First, a light pulse shall be expressed with a degree type.
[0019]
[Equation 2]

$$q(T,Z)=\eta(Z)\,\mathrm{sech}[\eta(Z)\{T-T_0(Z)\}]\,\mathrm{epx}[-ik(Z)T+i\theta_0(Z)] \quad \cdots (2)$$

[0020] It means changing adiabatically as the parameters eta and k showing the amplitude (or width of face) and rate (or frequency) of 1-soliton solution of a nonlinear Schrodinger equation spread this equation (2). Moreover, center position T0 of a soliton And phase theta 0 It is the function of Z. Said formula (2) is substituted for a formula (1), and a degree type is further obtained by using a perturbation backscattering method.
[0021]
[Equation 3]

$$\begin{cases} \dfrac{d\eta}{dZ} = 2\delta\eta - 2\beta\eta\left(\dfrac{1}{3}\eta^2 + k^2\right) + \dfrac{4}{3}\gamma\eta^3 + S_\eta(Z), & \dfrac{dk}{dZ} = -\dfrac{4}{3}\beta k\eta^2 + S_k(Z) \\ \dfrac{d\theta_0}{dZ} = \dfrac{1}{2}(\eta^2 - k^2) + T_0\dfrac{dk}{dZ} + S_{\theta 0}(Z), & \dfrac{dT_0}{dZ} = -k + S_{T_0}(Z) \end{cases} \quad \cdots (3)$$

[0022] Here, it is Si. (Z), and (i=eta, k and T0 and theta 0) express the effectiveness of the random kick which a noise gives to a soliton parameter, and is the autocorrelation-function <Si. (Z) Si (Z')> is given by the degree type.
[0023]
[Equation 4]

$$\langle S_i(Z) S_i(Z') \rangle = 2\mu_i \delta(Z - Z') \quad \cdots (4)$$

$$\begin{cases} \mu_\eta = \dfrac{(G-1)\hat{\eta}}{2N_0 Z_a} = 3\mu, & \mu_k = \dfrac{(G-1)\hat{\eta}}{6N_0 Z_a} \equiv \mu \\ \mu_{T_0} = \dfrac{(G-1)\pi^2}{24\hat{\eta}^3 N_0 Z_a} = \dfrac{\pi^2}{4\hat{\eta}^4}\mu, & \mu_{\theta_0} = \dfrac{(G-1)(\pi^2+12)}{72\hat{\eta} N_0 Z_a} = \dfrac{\pi^2+12}{12\hat{\eta}^2}\mu \end{cases}$$

ここで、δ（Z）はデルタ関数であり、Gは増幅器の電力利得、N_0 は単位エネルギー当たりの光子数、Z_a は分散距離 z_0 を単位として測った増幅器間隔、$\hat{\eta}$はソリトンの振幅（または幅）を表す。
$\delta = \beta = \gamma = 0$、$S_\eta = S_k = S_{T_0} = S_{\theta_0} = 0$ とおいて、式（3）をZ＝0における初期値（η, k, T_0, θ_0）＝（$\hat{\eta}_0$, $\hat{k}_0$, $\hat{T}_{00}$, $\hat{\theta}_{00}$）

[0024] If it solves also as **, it will become the following formula (5).
[0025]
[Equation 5]

$$\eta = \hat{\eta}_0, \quad k = \hat{k}_0, \quad T_0 = \hat{T}_{00} - \hat{k}_0 Z, \quad \theta_0 = \hat{\theta}_{00} + \frac{1}{2}(\hat{\eta}_0^2 - \hat{k}_0^2)Z \quad \cdots (5)$$

となる。式（5）の初期位相$\hat{\theta}_{00}$は光ソリトンパルスが非線形シュレディンガー方程式に従って伝搬する限り保存される量であり、パルス中でTに依らず一定である。

[0026] This is the basic principle of the PE of this invention. Moreover, in the above-mentioned formula (3), by choosing with beta=3delta+2gamma, = (eta, k) (1 0) becomes a stable point asymptotically, and can perform transmission control of a soliton.
[0027]
[Equation 6]
次に、（η, k, T_0, θ_0）＝（$\hat{\eta}+\Delta\eta$, $\hat{k}+\Delta k$, $\hat{T}_0+\Delta T_0$, $\hat{\theta}_0+\Delta\theta_0$）において式（3）に代入し、$\beta = 3\delta + 2\gamma$の条件の下で、（$\hat{\eta}$, $\hat{k}$, $\hat{T}_0$, $\hat{\theta}_0$）＝（1, 0, 0, Z／2）の周りで線形化すると、

$$\begin{cases} \dfrac{d(\Delta\eta)}{dZ} = -4\delta\Delta\eta + S_\eta, & \dfrac{d(\Delta k)}{dZ} = -\dfrac{4}{3}\beta\Delta k + S_k \\ \dfrac{d(\Delta T_0)}{dZ} = -\Delta k + S_{T_0}, & \dfrac{d(\Delta\theta_0)}{dZ} = \Delta\eta + S_{\theta_0} \end{cases} \quad \cdots (6)$$

[0028] It becomes. Said formula (6) is delta eta, delta theta0, and delta k and delta T0. It means having joined together, respectively. First, the effectiveness of the transmission control by the effect distorted the first stage, the frequency filter, and nonlinear gain of pulse shape is examined that there is no amplifier noise.

[0029]
[Equation 7]
式（６）において、$S_\eta = S_k = S_{T_0} = S_{\theta_0} = 0$とおき、$Z=0$における波形歪の初期値を（$\Delta\eta$，$\Delta k$，$\Delta T_0$，$\Delta\theta_0$）＝（$\tilde{\eta}$，$\tilde{k}$，$\tilde{T}_0$，$\tilde{\theta}_0$）とおく。伝送制御を行わない場合、及び行った場合の式（６）の初期値問題の解は次式で与えられる
。

$$\begin{cases} \Delta\eta = \tilde{\eta} & \longleftrightarrow \tilde{\eta}\, e^{-4\delta Z} \\ \Delta k = \tilde{k} & \longleftrightarrow \tilde{k}\, e^{-4\beta Z/3} \\ \Delta T_0 = \tilde{T}_0 - \tilde{k} Z & \longleftrightarrow \tilde{T}_0 - \dfrac{3\tilde{k}}{4\beta}\left(1 - e^{-4\beta Z/3}\right) \\ \Delta\theta_0 = \tilde{\theta}_0 + \tilde{\eta} Z & \longleftrightarrow \tilde{\theta}_0 + \dfrac{\tilde{\eta}}{4\delta}\left(1 - e^{-4\delta Z}\right) \end{cases} \quad \cdots (7)$$

[0030] In not performing transmission control, when it performs transmission control to the center position and phase shift of a pulse from this formula (7) to increasing in proportion to travelling distance, it turns out that only a gap of the constant decided by initial distortion is produced. Next, the effect of the spontaneous emmision noise of amplifier and the effectiveness of transmission control are examined that there is no initial distortion in pulse shape.
[0031] Since Si of the right-hand side of said equation (6), and (i=eta, k and T0 and theta 0) express the random rocking force, said equation (6) turns into a Langevin equation in this case. Si It is [0032], when the square average (distribution) of (delta eta, delta k, delta T0, and deltatheta0) at the time of carrying out is calculated when not performing transmission control and noting that an autocorrelation function is given by said formula (4).
[Equation 8]

$$\begin{cases} \langle \Delta\eta^2(Z) \rangle = 2\mu_\eta Z & \longleftrightarrow \dfrac{\mu_\eta}{4\delta}\left(1 - e^{-8\delta Z}\right) \\ \langle \Delta k^2(Z) \rangle = 2\mu_k Z & \longleftrightarrow \dfrac{3\mu_k}{4\beta}\left(1 - e^{-8\beta Z/3}\right) \\ \langle \Delta T_0^2(Z) \rangle = \dfrac{2}{3}\mu_k Z^3 + 2\mu_{T0} Z & \longleftrightarrow \dfrac{9\mu_k}{64\beta^3}\left(8\beta Z - 9 + 12e^{-4\beta Z/3} - 3e^{-8\beta Z/3}\right) + 2\mu_{T0} Z \\ \langle \Delta\theta_0^2(Z) \rangle = \dfrac{2}{3}\mu_\eta Z^3 + 2\mu_{\theta_0} Z & \longleftrightarrow \dfrac{\mu_\eta}{64\delta^3}\left(8\delta Z - 3 + 4e^{-4\delta Z} - e^{-8\delta Z}\right) + 2\mu_{\theta_0} Z \end{cases} \quad \cdots (8)$$

[0033] It becomes. It is a phase shift deltatheta0 like [formula / this / (8)] the gap deltaT0 (timing jitter by the Gordon-Haus effectiveness) of the center position of the pulse by the amplifier noise. It turns out that it is stopped by the effectiveness which is proportional to a transmission distance by performing transmission control about the effectiveness that fluctuation also increases in proportion to the cube of a transmission distance. Moreover, deltaT0 beta is deltatheta0. It is stopped, so that delta is large respectively.
[0034] Furthermore, it asks for the transmission distance of the IM-DD method using an optical soliton, and an PSK method, and the relation of an error rate from said formula (8). deltaT0 And deltatheta0 Probability distribution is assumed to be what is expressed with Gaussian distribution. Moreover, with an IM-DD method, it is T0. When half-power-width 2loge (root2+1) of a pulse shifts 1/2 or more, it is regarded as an error, and with an PSK method, it is theta 0. It will be considered that the case where it shifts pi/2 or more is an error. At this time, it is an error rate Pe. It is [0035], respectively.
[Equation 9]

$$P_e^{PSK} = \mathrm{erfc}\left[\frac{\pi/2}{\sqrt{2\langle\Delta\theta_0^2(Z)\rangle}}\right],\quad P_e^{IM-DD} = \mathrm{erfc}\left[\frac{\log_e(\sqrt{2}+1)}{\sqrt{2\langle\Delta T_0^2(Z)\rangle}}\right] \quad \cdots (9)$$

で与えられる。ここでｅｒｆｃ［・］は誤差補関数である。

[0036] Moreover, mu of said formula (4) is [0037].
[Equation 10]

$$\mu = \frac{4\pi^3 c^3 h}{3\{2\log_e(\sqrt{2}+1)\}^3}\cdot\frac{n_2\hat{\gamma}\tau_s^3}{\lambda^6 D^2 A_{eff}} \quad \cdots (10)$$

で与えられる。ここで、ｃは光速、ｈはプランク定数、n_2 はカー係数、$\hat{\gamma}$は電力損失係数、τ_s はパルスの電力半値幅、λは波長、Ｄは群速度遅延、A_{eff} はコアの実効断面積である。具体例として、n_2 ＝３．２×１０$^{-16}$ ［ｃｍ^2 ／Ｗ］、$\hat{\gamma}$＝０．２［ｄＢ／ｋｍ］、τ_s ＝２０［ｐｓ］、λ＝１．５５［μｍ］、Ｄ＝１．０［ｐｓ／（ｎｍ・ｋｍ）］、A_{eff} ＝３０［μｍ^2 ］とした時に、式（９）から求めた誤り率を図３に示す。このとき、分散距離z_0 は１０１［ｋｍ］である。

[0038] Drawing 3 shows that a transmission distance can be extended by the transmission control by the frequency filter and nonlinear gain. Moreover, when not performing transmission control, it turns out that the error rate of the IM-DD method to an amplifier noise and an PSK method is almost the same. Next, the effect of the interaction between contiguity solitons is explained. When a phase is the same as a contiguity soliton (i.e., when it is an inphase), a soliton is drawn mutually and causes a collision. Moreover, when the phase has shifted only in pi, in the case of opposition, a soliton is repelled mutually, and pulse separation spread. In any case, the center position of a pulse shifts, and it becomes the cause of a decode error. A perturbation backscattering method considers the effect of an interaction. First, an adjoining soliton will be expressed with a degree type.
[0039]
[Equation 11]

$$q(T, Z) = \sum_{j=1}^{2} A_j(Z)\,\mathrm{sech}[A_j(Z)\{T - T_j(Z)\}]\,e^{-iB_j(Z)\{T-T_j(Z)\}+iD_j(Z)} \quad \cdots (11)$$

[0040] The parameter Aj by which the soliton of this formula (11) is characterized, Bj, Tj, and Dj The perturbation backscattering method for having taken the interaction with a contiguity soliton into consideration for changing adiabatically to Z is applied, and it is [0041].
[Equation 12]

$$\begin{cases} \dfrac{dA}{dZ} = 2\delta A - 2\beta A\left(\dfrac{1}{3}A^2 + B^2\right) + \dfrac{4}{3}\gamma A^3, \quad \dfrac{dB}{dZ} = -\dfrac{4}{3}\beta A^2 B \\ \dfrac{d(\Delta A)}{dZ} = 8A^3 e^{-A\Delta T}\sin(\Delta\theta) + 2\delta\Delta A - 2\beta\{(A^2+B^2)\Delta A + 2AB\Delta B\} + 4\gamma A^2\Delta A \\ \dfrac{d(\Delta B)}{dZ} = 8A^3 e^{-A\Delta T}\cos(\Delta\theta) - \dfrac{4}{3}\beta A(A\Delta B + 2B\Delta A) \\ \dfrac{d(\Delta T)}{dZ} = -\Delta B, \quad \dfrac{d(\Delta\theta)}{dZ} = A\Delta A - \dfrac{4}{3}\beta A^2 B\Delta T \end{cases} \quad \cdots (12)$$

[0042] ******. Here, they are A= (A1+A2)/2, B= (B1+B-2)/2, deltaA=A1-A2, deltaB=B1-B-2, deltaT=T1-T2, deltaD=D1-D2, and delta theta=BdeltaT+delta D. Moreover, in drawing a formula (12), approximation of |deltaA|<<A, |deltaB|<<B, AdeltaT>>1, and |delta A|delta T<<1 was used. Moreover, below, initial condition in Z= 0 in the case of solving the initial value problem of a formula (12) is made

into = (A, B, delta A, delta B, delta T, delta theta) (1, 0, 0, 0, T0, and theta 0).
[0043] When not performing transmission control, the initial value problem of said formula (12) can be solved analytically. It is [0044] when two solitons are inphases (theta0 =0) in Z= 0.
[Equation 13]

$$\Delta T(Z) = T_0 + 2\log_e|\cos(2e^{-T_0/2}Z)|,\quad \Delta\Theta(Z) = 0 \qquad \cdots (13a)$$

となる。一方、Z＝0で2つのソリトンが逆相（$\Theta_0 = \pi$）の場合には、

$$\Delta T(Z) = T_0 + \log_e\left\{\frac{1}{2}\cosh(4e^{-T_0/2}Z)\right\},\quad \Delta\Theta(Z) = \pi \qquad \cdots (13b)$$

[0045] It becomes. when |deltaT-T0 | shifts in said formula (13) about an IM-DD method more than half-power-width 2log [(root2) +1] of a pulse (one soliton shifts only one half of half-value width at this time), ****** an error arises -- the transmission distance at that time -- Ze [** -- if it carries out -- 0046]

[Equation 14]

$$Z_e = \frac{\cos^{-1}(\sqrt{2}-1)}{2e^{-T_0/2}}\ (\text{同相の場合}),\quad Z_e = \frac{\cosh^{-1}(5+4\sqrt{2})}{4e^{-T_0/2}}\ (\text{逆相の場合}) \qquad \cdots (14)$$

[0047] It becomes. On the other hand, by the PSK method of this invention, when an initial phase difference is 0 or pi, phase contrast deltatheta does not change with transmission distances. When transmission control is performed, said formula (12) is numerically solved with a Runge-Kutta method, and it is Ze. And it asked for deltatheta (Z). Initial pulse separation T0 for which it asked by said formula (14) and numerical calculation Distance Ze which an error produces by the IM-DD method Relation is shown in drawing 4 . Moreover, also when transmission control is performed, phase contrast deltatheta does not change. Therefore, phase contrast does not change to the interaction between solitons, but the phase of a soliton is still more fixed in a pulse, and it turns out that the direction of an PSK method can make an error rate small compared with an IM-DD method since an information signal is discriminable also in the part of the skirt of a pulse.
[0048] Thus, the communication mode by the phase modulation using an optical soliton as a subcarrier was examined. The method of perturbation estimated quantitatively the effectiveness of the transmission control by the effect, the frequency filter, and nonlinear gain which the initial distortion of pulse shape, an amplifier noise, and the interaction between solitons exert on the center position and phase of a pulse, and the comparison of the IM-DD method using a soliton and an PSK method was performed.
[0049] Consequently, although great difference did not have the transmission characteristic of an PSK method to the amplifier noise compared with the IM-DD method, it became clear that it is hard to be influenced to the interaction between solitons. Moreover, it turned out that the effectiveness of transmission control over a noise is large. It is a future technical problem to perform the comparison with the digital PE (PSK method) which puts an information signal on a phase among coherent light communication modes, and to clarify the merits and demerits.
[0050] In addition, this invention is not limited to the above-mentioned example, and based on the meaning of this invention, various deformation is possible for it and it does not eliminate these from the range of this invention.
[0051]
[Effect of the Invention] As mentioned above, according to this invention, the following effectiveness can be done so as explained to the detail.
Much information can be transmitted from (1) and more stable signal transduction can be performed compared with a characteristic value communication link.
[0052] (2) As for the communication link by phase-modulation control of this optical soliton,

development is expected as the basic trunk for high-speed optical communication and multimedia, and high-reliability optical communication.

[Translation done.]

CLAIMS

[Claim(s)]
[Claim 1] In the correspondence procedure which is made to input an optical soliton into the propagation path which has the dispersibility and nonlinearity of an optical fiber etc., and is made to spread The initial phase of an optical soliton pulse is saved as long as an optical soliton pulse spreads according to a nonlinear Schrodinger equation. It is not based on time amount in a pulse, but an optical soliton is used as a subcarrier using a fixed property. The correspondence procedure using the optical soliton characterized by restoring to the information signal which performed the phase modulation of an optical soliton with the information signal, transmitted the information signal through the propagation path, and was transmitted based on the initial phase of an optical soliton.
[Claim 2] The correspondence procedure using the optical soliton characterized by putting an information signal on the phase of the pulse which constitutes an optical soliton pulse train in the correspondence procedure using an optical soliton according to claim 1.
[Claim 3] The **** correspondence procedure for optical solitons characterized by performing transmission control of the parameter of an optical soliton and suppressing fluctuation of a gap of the center position of a pulse, and a phase shift in the correspondence procedure using an optical soliton according to claim 2.
[Claim 4] The **** correspondence procedure for optical solitons characterized by putting an information signal on the phase contrast between contiguity solitons in the correspondence procedure using an optical soliton according to claim 1.
[Claim 5] The **** correspondence procedure for optical solitons characterized by transmitting 0 or pi, and a nothing information signal for an initial phase difference in the correspondence procedure using an optical soliton according to claim 4.
[Claim 6] In the communication system which is made to input an optical soliton into the propagation path which has the dispersibility and nonlinearity of an optical fiber etc., and is made to spread (a) A phase modulation means to modulate the phase of an optical soliton corresponding to an information signal, (b) -- the propagation path which transmits an information signal, a phase detection means to detect the phase of an optical soliton based on the initial phase of the (c) optical soliton, and (d) -- the communication system using the optical soliton possessing a recovery means to restore to the information signal transmitted from the phase of the optical soliton.
[Claim 7] Communication system using the optical soliton which possesses the control unit of the parameter of the optical soliton which suppresses fluctuation of a gap of the center position of a pulse, and a phase shift in the communication system using an optical soliton according to claim 6.

[Translation done.]